Course Description

- **Instructor**
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- **Recommended prerequisite**
  - Manufacturing process I (21-418)

- **Class time**
  - Sunday-Tuesday 18:00-19:30

- **Course evaluation**
  - Mid-term (25%)
  - Final exam (40%)
  - Quiz (5%)
  - Exercise (Manufacturing Lab.) (30%)
Session reference

- **Reference:**

Course Description (Continued.)

- **Contents:**
  - Product development in the changing Global world
  - Stages of Product Development
  - The Structure of the Product Design Process
  - Early design: Requirement definition and conceptual Design
  - Trade-off analyses: Optimization using cost and utility Metrics
  - Detailed design: Analysis and Modeling
  - Design Review: Designing to Ensure Quality
  - Production System: Strategies, planning, and methodologies
  - Production System Development
  - Planning and Preparation for Efficient Development
  - Supply chain: Logistics, packaging, supply chain, and the environment
Trade-off analyses: Optimization using cost and

- Early Design:

Product Functional Requirements and Functional Decomposition

- Functional modeling
Functional Decomposition and the Axiomatic Approach

- AD gives a means of clarifying and focusing both the product’s functions and the objectives that the design should meet.

- The axiomatic approach provides a compact visual way of expressing the design intent and the overall design objective.

- Functional Requirements are defined as the minimum number of independent mandatory requirements that completely characterize the design objectives for a specific need.

- If possible, they must be independent of each other at every level in the design hierarchy.

\[ \{FR\} = \begin{pmatrix} (FR)_1 \\ \vdots \\ (FR)_n \end{pmatrix} \quad \text{and} \quad \{DP\} = \begin{pmatrix} (DP)_1 \\ \vdots \\ (DP)_n \end{pmatrix} \]

\[ \{FR\} = [A]\{DP\} \]

\[ [A] = \begin{bmatrix} A_{11} & A_{12} & \ldots & A_{1n} \\ A_{21} & A_{22} & \ldots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \ldots & A_{nn} \end{bmatrix} \]
Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - There are three types of solutions to the problem.
  - The first type of solution is the one that satisfies Axiom 1 and is attained when \([A]\) is a diagonal matrix. This is called the uncoupled solution.
  - The second type of solution always violates Axiom 1. In this case and the solution is called coupled.
  - The third solution is called a decoupled solution, and the independence of the FRs can be assured if we arrange the DPs in a certain order to arrive at the design matrix.

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Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - Phrasing of the Functional Requirements
  - “Tow a disabled automobile from one location to another;”
  - “Transport a disabled automobile from one location to another;”
  - “Move a disabled automobile from one location to another.”
Product Functional Requirements and Functional Decomposition

- Functional Decomposition and the Axiomatic Approach: Two Axioms

- (FR)11 = Place one carton into the system

- (FR)12 = Maintain position of carton

- (FR)13 = Close the carton’s flaps

- (FR)14 = Tape carton

- (FR)15 = Release carton

- (FR)16 = Remove sealed box from system
Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - (DP)\(_{11}\) = means to place carton into system
  - (DP)\(_{12}\) = means to maintain position of carton
  - (DP)\(_{13}\) = device to close the carton’s flaps
  - (DP)\(_{14}\) = taping mechanism
  - (DP)\(_{15}\) = means to release carton
  - (DP)\(_{16}\) = carton removal device
Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - *(FR)111 = Orient carton*
  - *(FR)112 = Propel one carton into the system*

- with the corresponding design parameters:
  \[
  \begin{pmatrix}
  (FR)_{111} \\
  (FR)_{112}
  \end{pmatrix}
  =
  \begin{pmatrix}
  x & 0 \\
  x & x
  \end{pmatrix}
  \begin{pmatrix}
  (DP)_{111} \\
  (DP)_{112}
  \end{pmatrix}
  \]
- *(DP)111 = Carton orienting device*
- *(DP)112 = Carton insertion (forward motion) device*
Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - **Intelligent V-Bending Machine**
  - The objective is to develop a procedure that produces a curved metal part of constant thickness from a thin, flat sheet of metal.

- **The generation of the means to satisfy this objective is governed by certain physical laws**

- **The corresponding DP is a procedure that produces the curved part.**

Advanced Manufacturing Laboratory, Department of Industrial Engineering, Sharif University of Technology
Product Planning & Development (21423), Session #12
Product Functional Requirements and Functional Decomposition

- Functional Decomposition and the Axiomatic Approach: Two Axioms
  - Intelligent V-Bending Machine
  - The moment $M_0$ is sufficiently high so that it causes the plate to undergo permanent deformation at the corresponding bend angle $\theta_0$.

- Corresponding to $\theta_0$ is a displacement $X_a$ under the applied force $F_0$ When $M_0$ is released, however, there is a certain amount of spring-back to a bend angle $\theta_f < \theta_0$.

- Corresponding to $\theta_f$ is a displacement $\Delta X_a$, which is the amount of permanent deformation under the point where the force was applied.

- From classical beam/plate theory, it is known that $X_a \sim \theta \sim F/EI$, $M \sim F$ and, therefore, $M/\theta \sim EI$, where $E$ the Young's modulus and $I$ is the moment of inertia of the cross section.

- For a fixed method of supporting the beam/plate, we have that

  \[
  M_0 = F_0 d/2 \\
  \theta_0 = \tan^{-1}(X_a/d) \\
  \theta_f = \tan^{-1}(\Delta X_a/d)
  \]

If we are able to measure $F_0$ and $X_a$ (and, consequently, $\Delta X_a$), then we have a means of controlling the process.
Product Functional Requirements and Functional Decomposition

- **Functional Decomposition and the Axiomatic Approach: Two Axioms**
  - **Intelligent V-Bending Machine**

\[
\theta_f = \theta_o - \frac{M_o}{\tan^{-1}(d/EI)} \cdot \tan^{-1}(X_d/d) - \frac{F_o d/2}{\tan^{-1}(d/EI)}
\]

- We have three independent parameters:
  - \( M_o \), which is proportional to the applied force \( F_o \);
  - \( EI \), which is a function of a physical property of the material and the cross-sectional dimensions of the plate; and
  - \( \theta_f \), which is the resulting bend angle of the plate after the release of \( M_o \).

**Product Functional Requirements and Functional Decomposition**

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    - \( \theta_f \), which is the resulting bend angle of the plate after the release of \( M_o \).

\[
\begin{align*}
(FR)_1 &= M_o & \text{(Generate moment)} \\
(FR)_2 &= \theta_o & \text{(Bend and deform metal)} \\
(FR)_3 &= \theta_f & \text{(Release to final bend angle)}
\end{align*}
\]
Product Functional Requirements and Functional Decomposition

- Functional Decomposition and the Axiomatic Approach: Two Axioms
  - Intelligent V-Bending Machine
  - We have three independent parameters:
    - \( Mo \), which is proportional to the applied force \( Fo \);
    - \( EI \), which is a function of a physical property of the material and the cross-sectional dimensions of the plate; and
    - \( \theta_f \), which is the resulting bend angle of the plate after the release of \( Mo \).

\[
\begin{bmatrix}
  M_o \\
  \theta_o \\
  \theta_f 
\end{bmatrix} =
\begin{bmatrix}
  1 & 0 & 0 \\
  0 & 1 & 0 \\
  0 & 1 & -1 
\end{bmatrix}
\begin{bmatrix}
  F_o d/2 \\
  \tan^{-1}(X_a/d) \\
  F_o d/(2 \tan^{-1} EI) 
\end{bmatrix}
\]

Product Functional Requirements and Functional Decomposition

- Functional Decomposition and the Axiomatic Approach: Two Axioms
  - Intelligent V-Bending Machine

- In order to implement this design equation, the following procedure is employed.
  - The punch is brought down and the plate is subjected to a force \( F' o \), which results in a displacement under it of \( X'a \).
  - The punch is removed and \( \Delta X'a \) is measured. From these three measurements, we determine \( \tan^{-1} EI \).
  - We now apply a slowly increasing force \( Fo \) and continuously monitor \( Fo \) and \( Xa \) until their values produce the desired \( \theta_f \).
Project

- Product Functional Requirements